

THE IC

NEW
TECHNIQUES
OF
DIGITAL
TROUBLESHOOTING

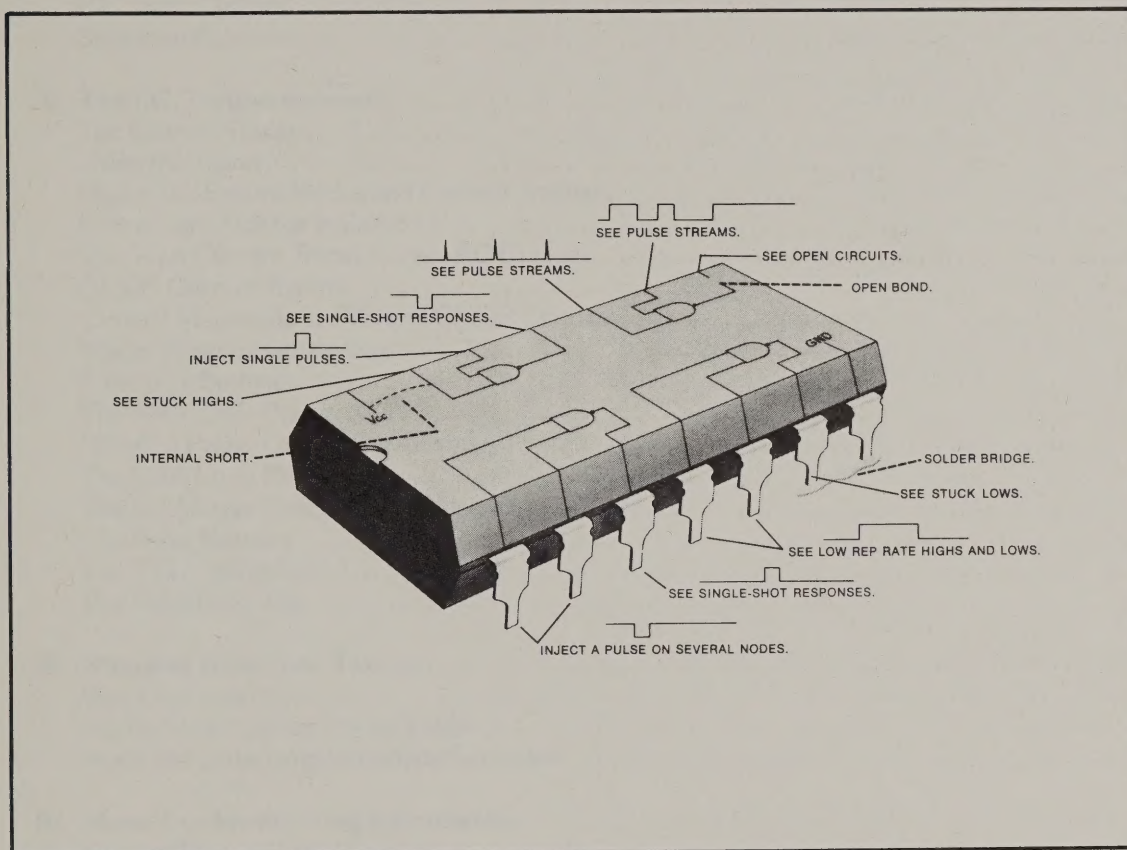
TROUBLESHOOTERS

APPLICATION NOTE 163-2



Application Note 163-2

New Techniques of Digital Troubleshooting



Using the IC Troubleshooters:

- Node and Gate Fault Analysis
- Current Tracing in Digital Circuits

New Techniques of Digital Troubleshooting



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- Node and Gate Fault Analysis
- Current Tracing in Digital Circuits

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Section I

Introduction - HP's Digital Troubleshooting Family

Digital circuits present their own troubleshooting problems; measurement problems quite different and unique from those encountered in analog circuitry, and yet it wasn't until 1969 that new troubleshooters like HP's 10525A Logic Probe were invented to simplify digital measurements. Tools like these have helped to re-direct the troubleshooters efforts toward circuit analysis rather than toward analyzing how to use analog tools to make meaningful measurements in digital circuits.

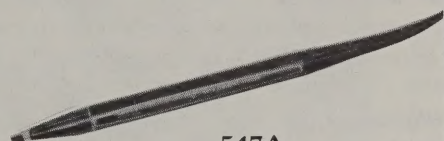
HP, and others, now have a wide variety of instruments specifically intended to help in the design, debugging, troubleshooting, and repair of complex digital circuits. Among them are logic analyzers, PC board testers, signature analyzers, and finally, a group of node and gate troubleshooting tools called the IC Troubleshooters.

THE IC TROUBLESHOOTERS

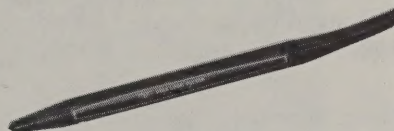
HP's hand-held IC Troubleshooters are a group of simple digital test and measurement tools. They are intended to be used at the node and gate level to precisely locate some very hard-to-find faults such as Vcc-to-ground shorts, solder bridges, and stuck buses.

In general, these tools are used to verify faults identified by our other instruments so that you can non-destructively repair your circuit quickly and easily. They are also used as test sets by field servicemen on-site. And finally, they are tools often found on the production line, and especially around PC board testers as accessories.

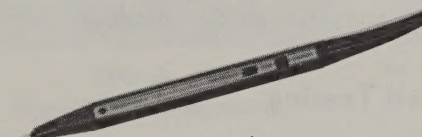
It takes circuit knowledge and skill to use simple tools like the IC Troubleshooters in digital troubleshooting. This applications note should enhance your ability to use probes, pulsers, current tracers, logic clips and logic comparators.



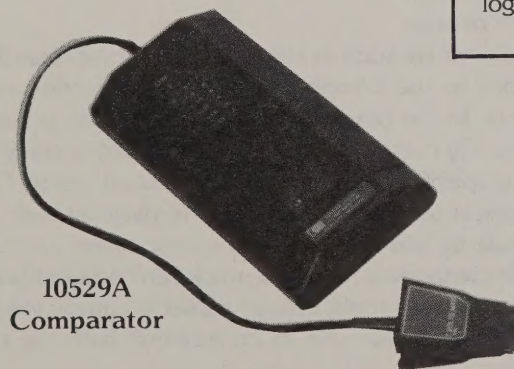
547A
Current Tracer



546A
Pulser



545A
Probe



10529A
Comparator



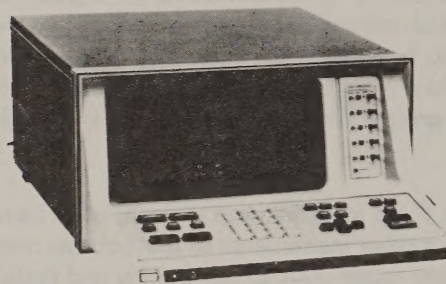
548A
Clip

HP's Other Digital Troubleshooting Tools

Hewlett-Packard produces a number of other test and measurement products for use in design, production and service areas. The IC Troubleshooters are used as accessories for some of these products or as primary troubleshooting tools on their own. The summaries below will help you see how these products fit your needs, and how the IC Troubleshooters fit into any troubleshooting situation.



1615A
Logic Analyzer



1610A
Logic Analyzer

Logic Analyzers

There are several models available to fit your specific applications with a variety of powerful operating features. The Model 1615A shown here enables you to do simultaneous time and state analysis, plus it has unique glitch analysis capability making it ideally suited for hardware/software troubleshooting applications.

HP's 1610A features 32 input channels, graph, store, and compare modes plus seven levels of sequential triggering for extensive software debugging.

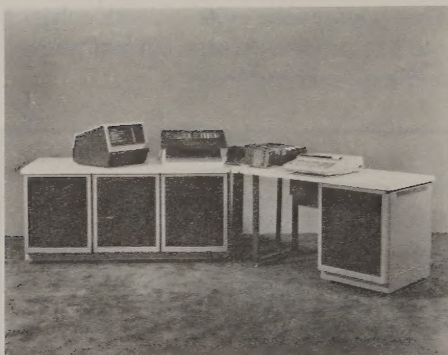
The IC Troubleshooters are valuable additions to logic analyzers in that they allow you to pinpoint faults such as stuck bus lines located during logic analysis, or to investigate faults using the stimulus-response techniques described later in this applications note.

For additional information on the use of logic analysis, HP publishes an applications note series. These notes contain interface and display information for various microprocessor and logic troubleshooting problems.

PC Board Testing

PC board testing is provided to speed up production test times of loaded boards, and to catch faults before boards reach final assembly or board exchange inventories.

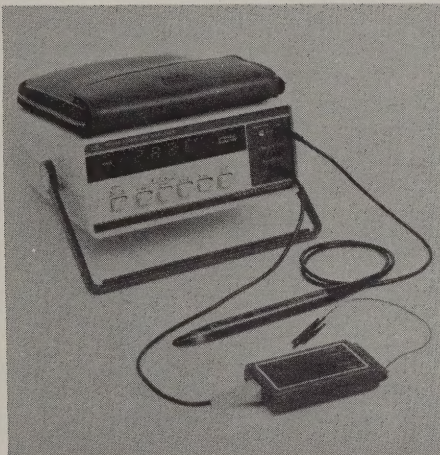
Board testers such as HP's DTS-70 identify board failure modes to the component level in production environments. In the case of the DTS-70, probes, pulsers and especially current tracers are often used to verify or pinpoint specific faults found by the board tester. Current tracing is used on board testers to pinpoint faults where a node or bus is stuck in one logic state, and the one node component holding it stuck can't be identified using voltage-based tools. A logic pulser is equally valuable in this situation for use in conjunction with the current tracer.



HP also produces a board tester, the Model 3060A, which uses Signature Analysis to debug in-circuit failures located on microprocessor-based PC boards. Applications Note AN-222-1 describes the advantages of this technique. Also, the section below on Signature Analysis describes more about this powerful tool and its applicability as part of a service strategy for microprocessors.

Signature Analysis

Signature Analysis is a troubleshooting technique that locates faults to the component level in microprocessor-based circuits. HP uses it in two areas: PC board testers, and portable test instruments. The Model 3060A pictured in the board test section above uses exactly the same technique to gather signatures as does the 5004A Signature Analyzer shown here.



**5004A
Signature Analyzer**

To use SA in the field for fault tracing to the component level, the field serviceman connects the 5004A Signature Analyzer to the faulty circuit and compares signatures taken with the analyzer to those signatures contained in documentation for the unit under test. There is one signature per node, and it is extremely accurate and repeatable.

The 3060A Board Tester and 5004A Signature Analyzer provide a means for you to implement a total service strategy. Whether your microprocessor boards are tested in the factory, in a field repair depot, or on-site, the signatures obtained are repeatable. So, boards tested on the 3060A in the factory can be repaired easily using the 5004A in the field.

HP Applications Note Series 222 gives you design details and other useful information to help you get started with Signature Analysis. As with our other products, we recommend using the IC Troubleshooters with SA products to verify faults, and to narrow bus faults to the one faulty component using current tracing and logic pulsing.

THE HISTORY OF THE UNITED STATES

The history of the United States is a story of growth and change. From the first settlers to the present day, the nation has evolved through various stages of development. The early years were marked by exploration and settlement, followed by a period of rapid expansion and industrialization. The American Revolution and the Civil War were pivotal moments in the nation's history, shaping its identity and values. The 20th century brought significant social and political changes, including the rise of the American Dream and the challenges of the Cold War. Today, the United States continues to grow and adapt to a rapidly changing world.

THE EARLY YEARS

The early years of the United States were a time of exploration and settlement. The first European settlers arrived in the late 15th and early 16th centuries, seeking new lands and opportunities. They established colonies along the eastern coast, which grew into the original thirteen states. The period was characterized by a mix of cooperation and conflict with Native American tribes. The American Revolution (1775-1783) was a defining moment, as the colonies fought for independence from British rule. The resulting Constitution established the framework for the new nation.

The 19th century was a period of rapid expansion and industrialization. The westward movement of settlers led to the acquisition of new territories, including the Louisiana Purchase and the Mexican-American War. The Industrial Revolution brought significant changes to the economy and society, with the rise of factories and urban centers. The Civil War (1861-1865) was a pivotal moment, as the nation fought to resolve the issue of slavery. The war resulted in the abolition of slavery and the preservation of the Union.

The 20th century brought significant social and political changes. The Progressive Era (1890s-1920s) saw the rise of reform movements aimed at addressing social issues. The Great Depression (1930s) was a period of economic hardship, leading to the New Deal policies of President Franklin D. Roosevelt. World War II (1941-1945) was a defining moment, as the United States fought against the Axis powers. The war resulted in the United States becoming a superpower and a leader in the world.

The 21st century has been a time of rapid technological advancement and global interconnectedness. The rise of the Internet and digital technology has transformed the way we live and work. The 9/11 attacks (2001) were a defining moment, leading to the War on Terror and the invasion of Iraq. The 2008 financial crisis and the subsequent recession have challenged the global economy. The current administration of President Donald Trump has brought significant changes to the nation's policies and direction.

The future of the United States is uncertain, but the nation's history suggests a path of growth and change. The challenges of the 21st century, including climate change, global inequality, and technological advancement, will require the nation to adapt and evolve. The American Dream, a vision of a better life for all, remains a guiding principle for the nation. The history of the United States is a story of resilience and hope, and it is a story that continues to unfold.

Section II

The IC Troubleshooters

This section contains several areas of interest to troubleshooters:

- a) The products we call the IC Troubleshooters
 - 1. 547A Current Tracer
 - 2. 546A Logic Pulser
 - 3. 545A Logic Probe
 - 4. 548A Logic Clip
- b) Troubleshooting tips for using each product.
- c) The kinds of digital faults that occur and the relative frequency of their occurrence.

This information is intermingled so that items useful for current tracing are covered under the 547A Current Tracer. Also, we begin with the tracer because it is the most powerful of the troubleshooters and requires more understanding for effective use.

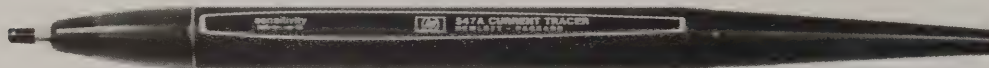
The Current Tracer: Getting An Edge on Digital Faults

The more an engineer or technician is familiar with a failed circuit, the more likely he can repair it quickly. There are many occasions, however, where a faulty circuit node is identified as “stuck”, and the troubleshooter is stuck too, having found many elements common to the node and too few ways to isolate the one bad component.

Current tracing can solve this problem, and still do it cheaply, quickly, and non-destructively. For example, it isn't necessary using current tracing to lift IC legs, cut traces, or force huge amounts of DC current down a path to locate (burn up) the short.

These destructive measures and others can be eliminated in favor of using a hand-held probe with a one-lamp indicator that glows when its tip is held over a **pulsing** current path. This means you can detect whether current is flowing at all (sometimes it isn't, as when a node driver is dead), or most importantly *where* the current is flowing. If a node is stuck LOW and the reason is a shorted input on one of the node's components, a very strong current flow exists between the node driver and the faulty component. For purposes of detection, the current has to be **pulsing** rather than DC, but this requirement is almost always met, and when it isn't, pulsing the faulty node with a logic pulser solves the problem.

To be sure, there are steps necessary to avoid “crosstalk”, to help troubleshoot multilayer boards, and *where* a circuit is pulsed can be important. This note tells you what we've learned about current tracing from the thousands of people who've used our troubleshooters for the past few years.



Using the Tracer

Troubleshooting

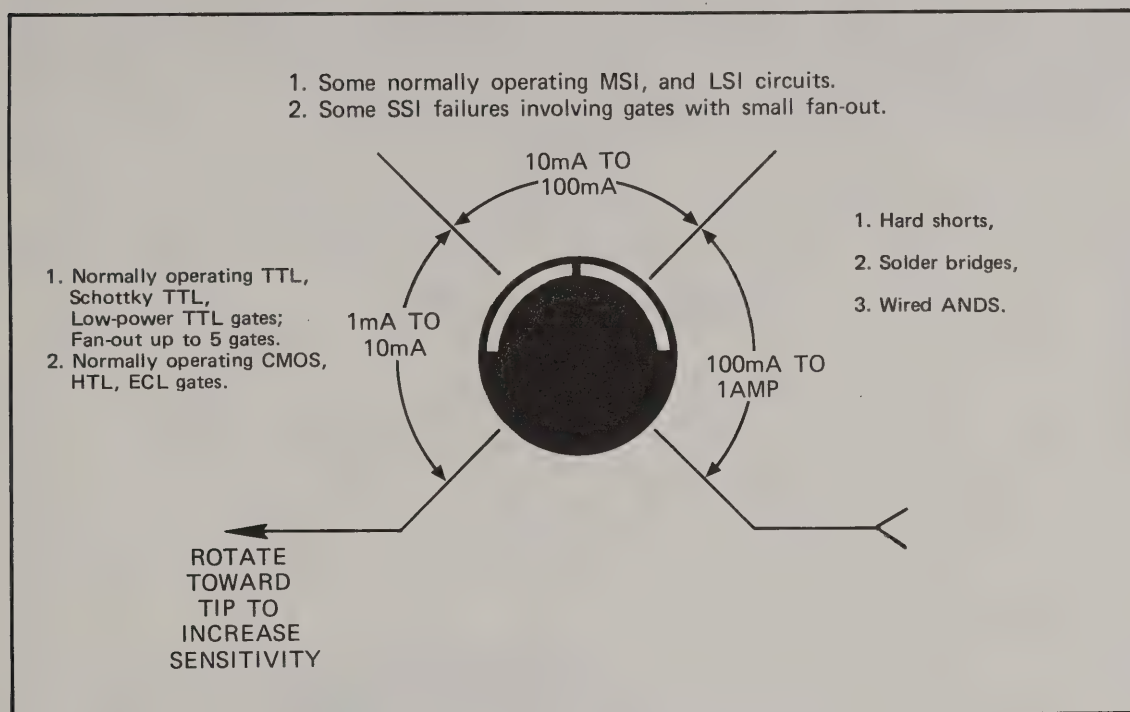
Usually the current tracer is the final test instrument employed to pinpoint a fault on a node. In general, the tracer pinpoints faults by following current flow after voltage or logic-state sensing devices have been used to narrow the fault area to a bus line, node, or PC-board trace. Since the area under test is probably stuck at a fixed voltage potential, only the use of current tracing will indicate an activity path that can be investigated. A node “stuck” in one state may be trying very hard to change state, and will therefore be carrying a great deal of current.

Sensitivity

The tracer's sensitivity can be varied over a great range of current values: from <1 mA to >1 Amp. It is critical to troubleshooting success to set the sensitivity correctly using the following steps:

1. Select the bad node, gate, or signal path to be traced
2. Place the tracer's tip at the node driver output
3. Align the tip (see Tracer Troubleshooting Tips in this section)
4. Set the Sensitivity Control for half-brilliance on the indicator lamp
5. Leave the sensitivity control at the same setting until the fault is located or until test conditions change (e.g.; a 546A Logic Pulser is used to stimulate the node to raise the current level).

The diagram below and others that follow can be useful for determining where a fault is, or the nature of the fault. For example, if a TTL node is stuck and the **sensitivity control** is set roughly midway (≥ 50 mA) during current tracer reference setting, it is likely the node driver is good, and is driving current into a short circuit (Section IV of this applications note contains information about current flow in normal TTL gate outputs).

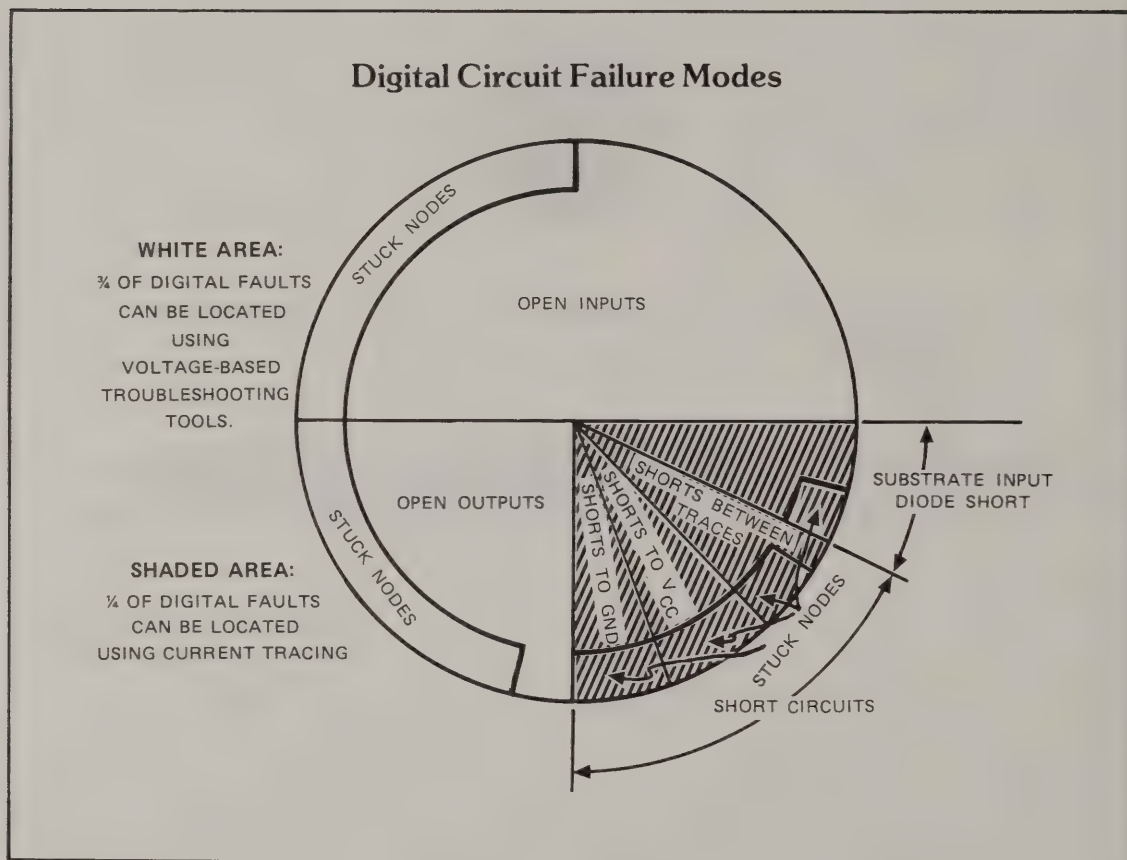


547A Current Tracer Sensitivity Control Setting versus Possible Circuit Condition

Digital IC Failure Modes and Current Tracing

IC's fail about three-fourths of the time by opening up at either the input or output. Failures of this kind can often be found using voltage-based methods such as probes, pulsers and clips.

Repairs to the other failures shown below benefit greatly by using current tracers. It is worth noting however, that the current tracer is generally the last tool used after a fault has been located down to a specific node or set of nodes. Further, the current tracer is most useful where the fault produces excessive current flow on the node, as in the case of a short to Vcc or ground; or in a case where two nodes are solder-bridged together.

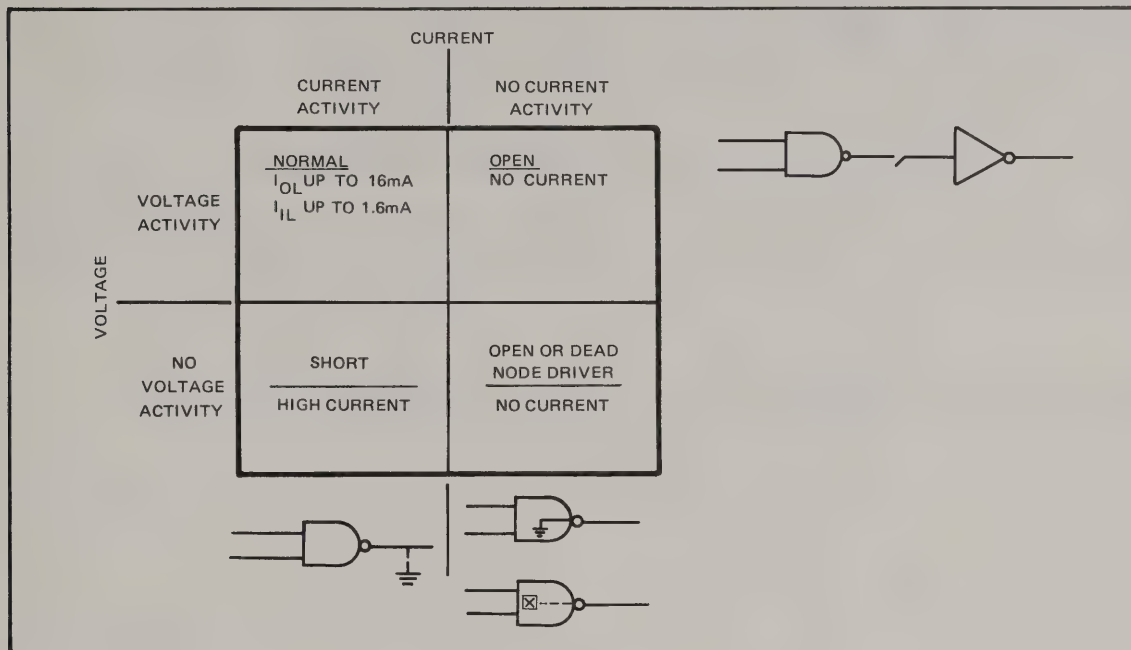


If there is little or no current flowing on the node, there is a likelihood of a dead driver (open output bond), or a lack of pulse activity in the circuit. In cases like this, use the probe and pulser to narrow down the symptoms of the fault, then use the pulser and tracer to investigate current flow on the node in question. There are occasions where a circuit appears faulty but isn't because a) the wrong node is under investigation, or b) the circuit schematic contains errors.

In any troubleshooting situation, knowledge of the circuit under test is critical to your success.

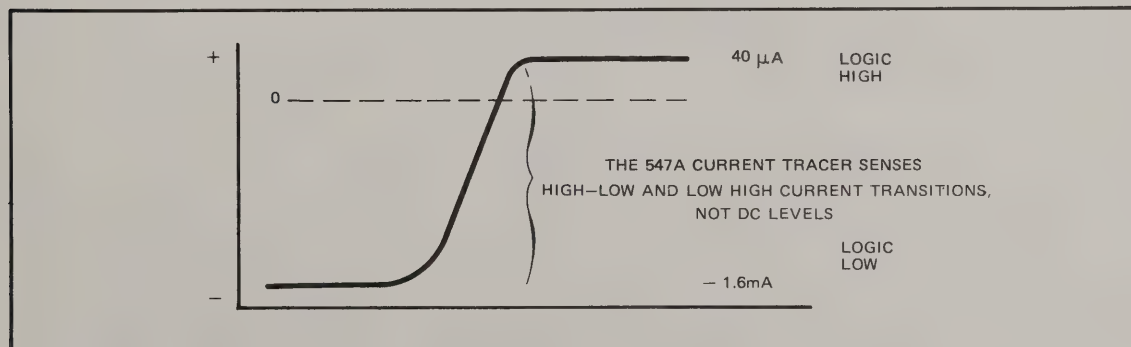
Current and Voltage in Failed IC's

Another way of classifying failures is contained in the illustration below. Note that in the upper left-hand corner there is both voltage and current activity present on a TTL circuit node, which indicates the circuit is likely to be operating normally. In the lower right-hand corner there is neither voltage nor current, indicating the driver is open, or dead.



When troubleshooting, the symptoms are seldom as clear as these are, and simple faults can often create perplexing symptoms. Nevertheless, a basic understanding of voltage **and** current provides the tools for troubleshooters to debug complex board faults.

The 547A Current Tracer Senses AC Current



Current magnitude of a standard TTL output with a fanout of one.

The HP-547A Current Tracer is an AC device. It detects and displays current pulses or current transitions and then stretches and displays them on its lamp. When a TTL output goes from Logic Low for example, the total current change is about 1.6 mA. The tracer senses the flux density in a conductor associated with this change and then displays the result. The tracer is not voltage-sensitive, and so responds only to current changes.

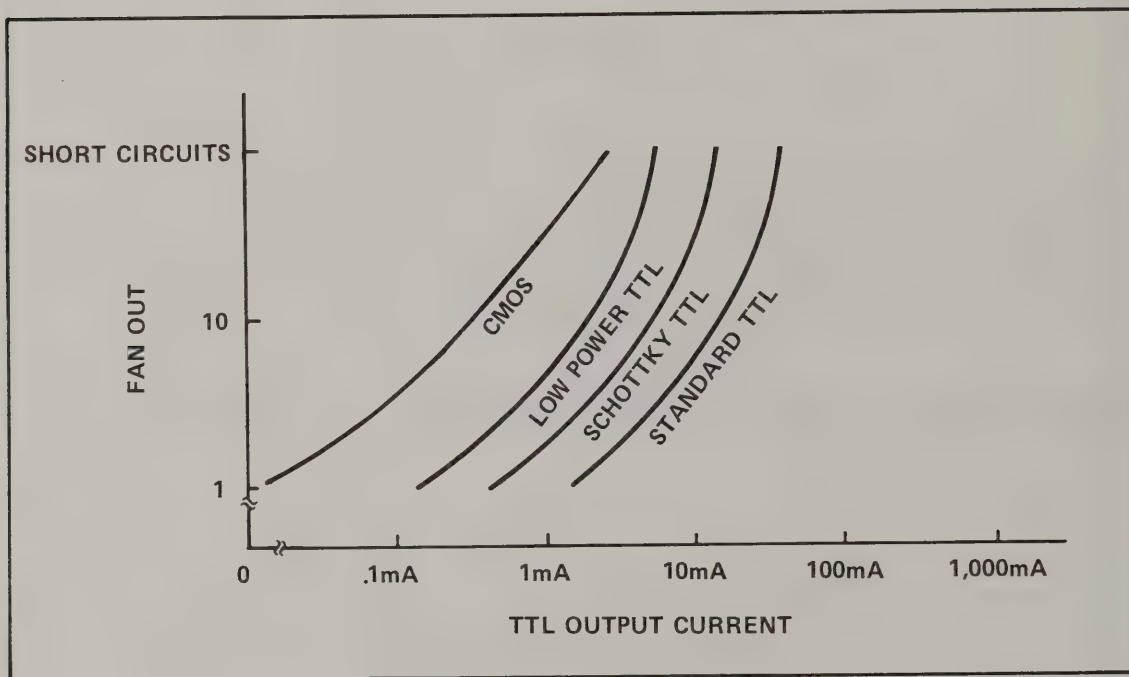
CMOS Current Tracing

On first glance it may seem the tracer would not be capable of sensing CMOS current flow. The tracer, however, easily "sees" Cmos current for the following reasons:

1. CMOS inputs charge up like capacitors
2. The charging current is greater than the threshold sensitivity of the tracer
3. CMOS IC manufacturers specify the DC current drawn by their devices, not the input charging current mentioned above
4. The 547A Current Tracer sensitivity exceeds the 1 mA specified
5. Most significantly, the current tracer is used to look at **faults** where the current is a great deal higher than normal.
6. Lastly, use of a 546A Logic Pulser effectively raises the in-circuit current to a much higher level to allow easy-to-follow tracing.

So, whether the circuit is TTL or CMOS, the tracer can sense AC current in it. The diagram below further supports this, and also shows the range of currents usually present in both of these IC families.

Current Magnitude in TTL and CMOS Circuits

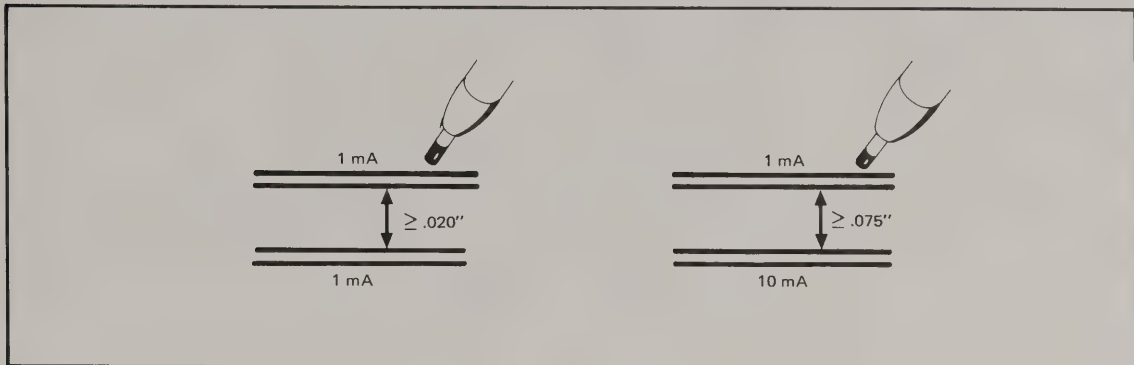


There is generally sufficiently high current for the tracer to easily differentiate fault paths from circuits containing "normal" current. A faulty circuit will usually carry at least an order of magnitude more current than one operating as the circuit designer intended. This is as true for CMOS circuits as it is for TTL. Faulty CMOS circuits carry almost as much current as the low power Schottky TTL example shown above.

Tracer Troubleshooting Tips

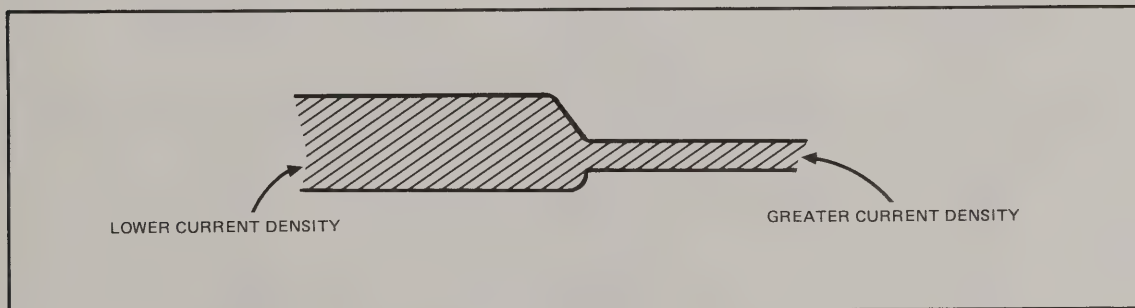
TRACE SPACING

The tracer's current sensing coil is very small, only .010" in diameter, although the protective plastic cover makes it appear larger. This means that PC board traces can be close together and tracing is still convenient. Two traces carrying identical current can be located .020" apart (edge-to-edge) and current flow between the two can be differentiated. If the two traces have a 10 to 1 current difference between them, spacing should exceed .075".



TRACE WIDTH

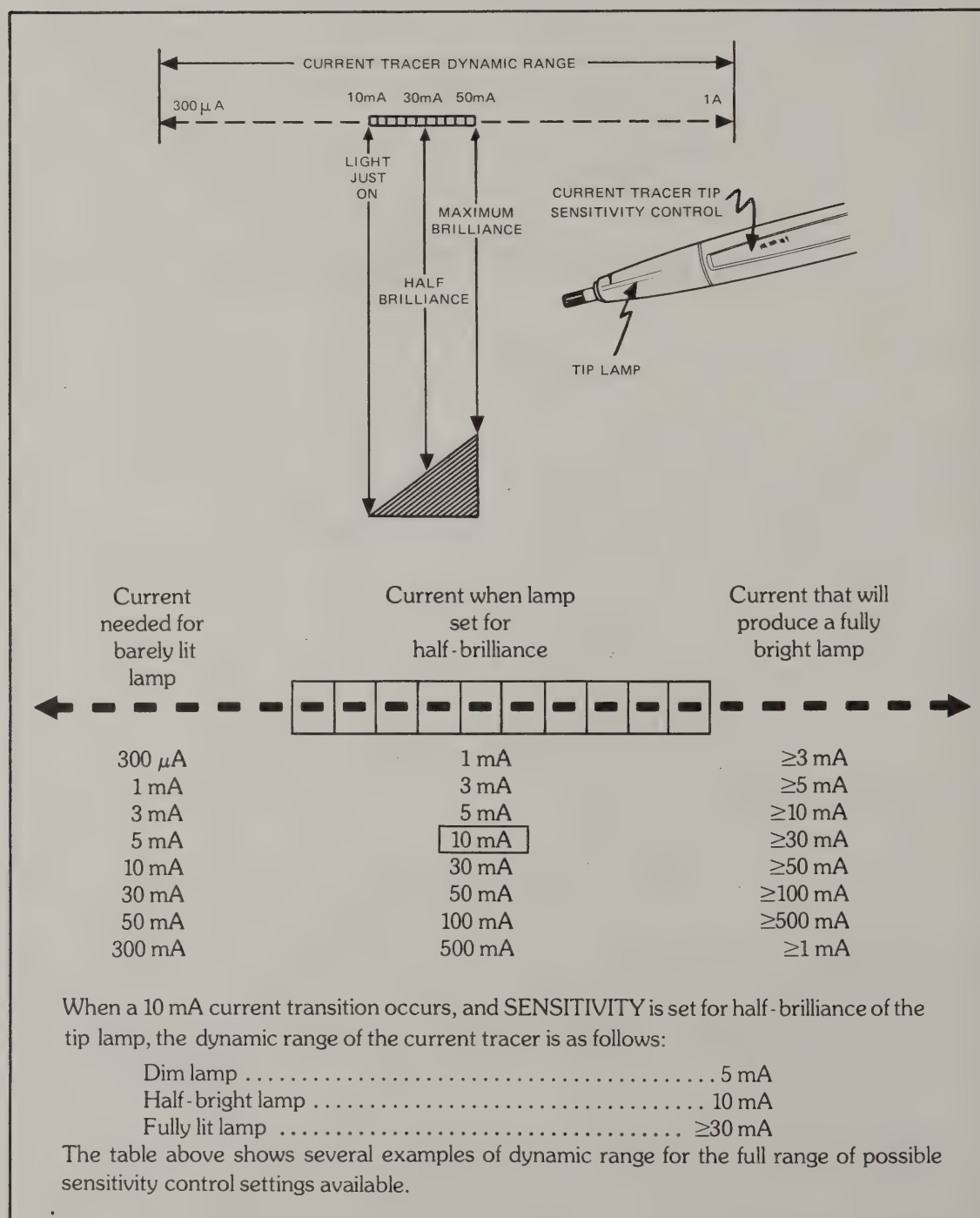
Traces that vary greatly in width cause flux density changes under the tracer's tip:



This can be important when tracing supply-to-ground shorts — the tracer's sensitivity might need to be varied slightly for better results.

Reference Setting

Setting a reference on a node identified as faulty is central to the current tracing process, but the setting for that particular node has little, if any, relevance for **other** nodes due to fan-out or variability in circuit interconnections. Also, the sensitivity control on the tracer allows you to "see" current as small as $300\ \mu\text{A}$ but there is virtually no upper limit. As the figure shows, if the sensitivity control is set so that 10 mA barely lights the tracer display, 30 mA will produce half-brilliance, and $\geq 50\ \text{mA}$ is the point where the lamp reaches full brilliance. Current in excess of 50 mA **also** produces full brilliance.



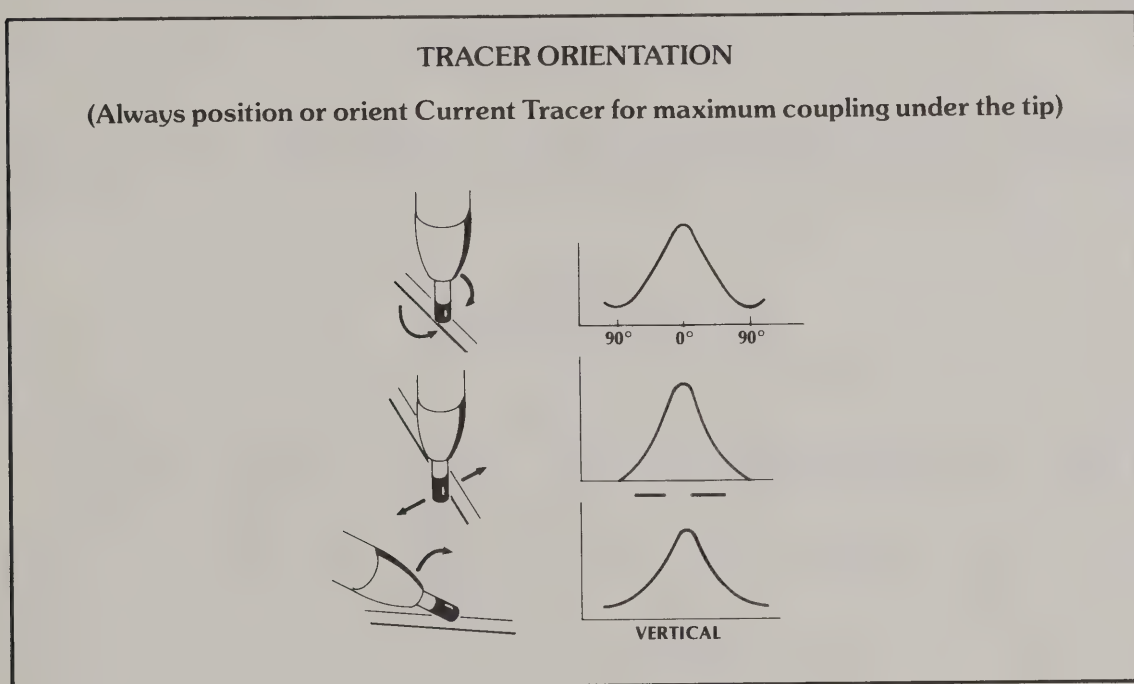
Crosstalk

One of the design challenges of the tracer was the need for sensitivity versus the danger of "crosstalk", i.e., seeing strong current flow in PC traces adjacent to the area under test.

There are several reasons crosstalk isn't as serious a problem as it may seem. Where crosstalk **is** a problem there are techniques to alleviate its effects.

Tip Alignment

The tracer tip is directional; that is, current in paths oriented 90° out of phase with the pickup coil tend to null out. So, proper tip orientation helps eliminate crosstalk from traces on different layers or at different angles.



REFERENCE SETTING AND TRACING

1. Adjust sensitivity control at reference point.
 - a. Usually at node driver output.
 - b. Set for half lamp brightness so that it's easier to see relative current changes.
2. Trace along current path or probe from IC pin to IC pin.
3. Use 546A Logic Pulser to excite the node if not active, or to overcome crosstalk.

Tip Shielding

The grounded metal case surrounding the tip along with an internal ferrite core allows signals directly under it to be coupled into the pickup coil, but signals not directly under the tip's open end are attenuated.

Sensitivity and Fault Current

Once a failed node has been identified, (and as you'll recall, these tend to have higher than normal current), the user sets the sensitivity to half-brilliance on the tracer lamp. This reference is maintained for troubleshooting on that particular node. The sensitivity setting is only relevant for the node under investigation and is changed only with foresight and caution.

Pin-to-Pin Tracing

In areas where a PC board has many traces side-by-side carrying substantial current (LED drivers are an example of parallel lines that carry relatively high current), the user can move away from these areas to trace current between components by setting a reference current level right on the node driver output pin. Then, simply go from pin-to-pin on the circuit's IC's instead of attempting to follow along the PC traces.

Use the Pulser

The faster the rise time of current pulses in the circuit, the easier it is for the tracer to display current. So, if crosstalk persists, use the HP-546A Logic Pulser to effectively "boost" viewable current in the circuit (reset current tracer sensitivity when using the Pulser to allow for the higher current flow).

**TTL AND CMOS
TYPICAL CURRENT LEVELS
(one output driving one input)**

LOGIC FAMILY	INPUT CAPACITANCE	STRAY CAPACITANCE	RISE TIME	AC CURRENT +	DC CURRENT CHANGE =	TOTAL CURRENT CHANGE
TTL	5 pF	5 pF	10 ns	5 mA + $I = 10 \text{ pF} \cdot 5V$ 10 ns	2 mA	7 mA
CMOS	5 pF	5 pF	50 ns	1 mA + $I = 10 \text{ pF} \cdot 5V$ 50 ns	40 pA	$\geq 1 \text{ mA}$

Avoid Power Supply Traces

Vcc and ground lines tend to be very "noisy" with respect to current spikes in digital circuits. These traces more often than not provide the highest level of "AC" current on a circuit board, so avoid them if possible, or, again, use the pulser to boost current on the node under test.

"Seeing" Through Multi-Layers

One of the real bonuses available using the tracer is the ability to "see" through multi-layers. This makes it possible to follow current paths through several layers to find heretofore undetectable faults. The techniques used are similar to non-multi-layer situations. That is, set a reference at the node driver output, keep proper tip orientation, and avoid crosstalk. The main task here is to increase sensitivity just enough to see the trace through the board, and to avoid "losing" the trace due to crosstalk, direction changes, etc.

The 546A Logic Pulser: Automatic Output and Programmability

Early in 1976, HP introduced the model 546A Logic Pulser as a companion to a whole new family of TTL/CMOS IC troubleshooters. The 546A added the following operating features that make it a virtual necessity in digital troubleshooting environments:

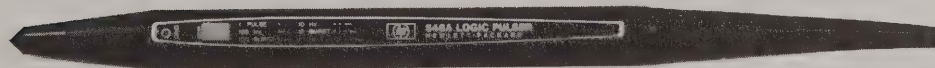
1. Automatic polarity output
2. Automatic pulse width
3. Automatic pulse amplitude
4. Six push-button programmable output modes

The 546A employs a complex custom integrated circuit containing 2,000 transistors including those used in an up and down counter, a ROM, a clock, and output sensors. This enables the pulser to pulse TTL gates in single steps, to drive CMOS at 100 Hz, or load a counter with a precise number of pulses. It also means the pulser provides versatile stimulus-response testing capability in both voltage and current applications for virtually any positive voltage logic family.

546A Logic Pulser Output Programming

OPERATION:			
PRESS AND RELEASE CODE BUTTON		o	
PRESS AND LATCH CODE BUTTON		o	
OUTPUT MODES:		TO OUTPUT EXACTLY 432 PULSES:	
o	SINGLE PULSE	1. 100 Hz BURST	o o o
o	100 Hz STREAM		98 ¹
o o	100 Hz BURST		100
o o o	10 Hz STREAM		100
o o o o	10 Hz BURST		100 ²
o o o o o	1 Hz STREAM		400
		2. 10 Hz BURST	o o o o o
			6 ¹
			10
			10 ²
			430
		3. SINGLE PULSE	o
		SINGLE PULSE	o
			1
			1
			432

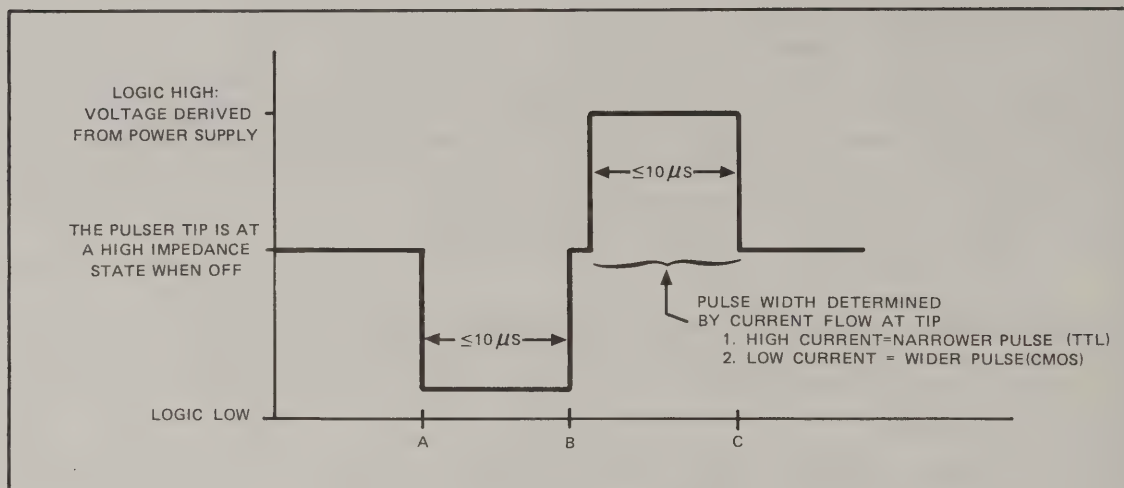
1. The first pulse burst is outputted after subtracting the pulses produced when programming the output.
2. Release the pulse button **during** the final burst. The pulser will complete the burst, then shut off.



HP 546A Pulser Output Waveform

Pulsing Into An Open Circuit

When the HP-546A Logic Pulser's push button is pressed, the pulser immediately outputs a single dual-polarity pulse. First it goes LOW, then it pauses and goes HIGH. When the tip is pulsed into an **open circuit** the pulse appears as shown below:



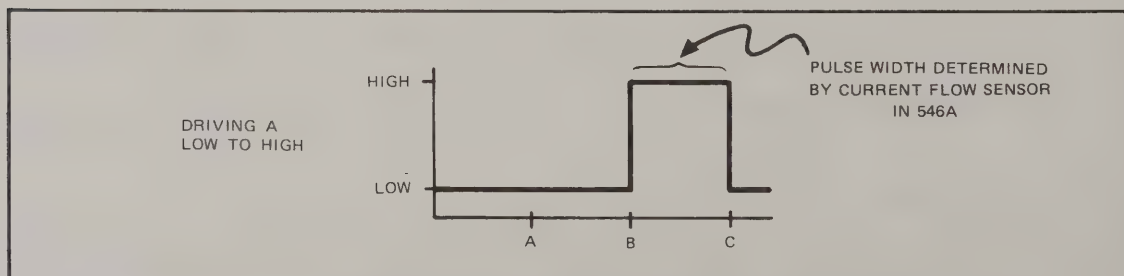
Automatic Pulse Width, Height, Polarity

The output pulse is shown above with the maximum width it attains. When pulsing into a circuit, the current flow through the pulser's tip is sensed by an output sensing circuit that shuts the pulser off.

The circuit turns the pulser off faster for TTL than CMOS. This keeps total energy low so as to eliminate any damage to the circuit being pulsed.

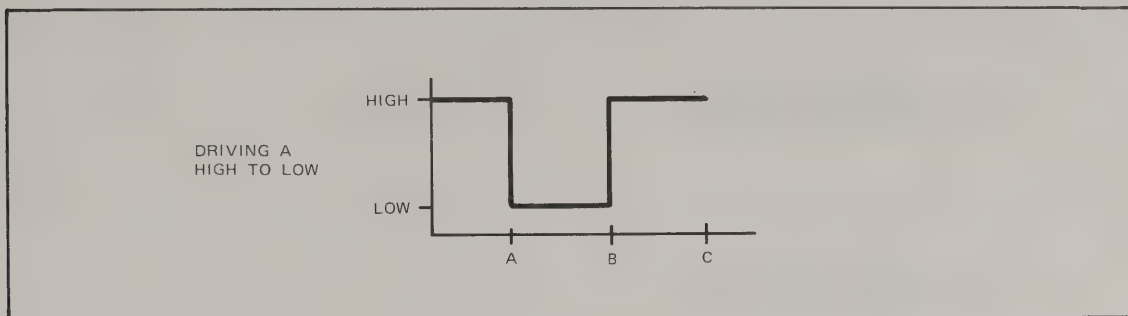
Pulse height or amplitude is derived from the power supply the pulser is connected to. For this reason, the pulser should always be powered from the circuit under test, or a power supply of the same voltage.

Pulsing Into a Load



- A. Driving a LOW node to a HIGH state: Since the node is already LOW, the pulser has no effect until it takes the circuit HIGH. When the Pulser goes HIGH, it has sufficient output drive to take any normal circuit or bus HIGH momentarily. Total energy is limited (low duty cycle), however, to exclude the possibility of circuit damage.

- B. Driving a HIGH node to a LOW state: Again, if a circuit is already HIGH, it can be taken LOW by the pulser. It cannot be driven higher if it's already at a HIGH state, so the high portion of the Pulser's output has no effect on the circuit.



The 545A Logic Probe: The “Digital Screwdriver”

In 1969 HP came out with the first purely functional measurement tool for troubleshooting digital circuits: the 10525A Logic Probe. Since then, the probe has become as commonly used by troubleshooters as the screwdriver is by mechanics: it is simple to use, versatile, and out of the way when not needed.

HP now has several probes, led by the multi-family model 545A, each intended to be highly useful in everyday applications. The greatest benefit of a probe is that the user can take it for granted: its greatest financial contribution, however, is that the probe replaces analog devices costing an order of magnitude more for most digital troubleshooting applications.

HP's IC troubleshooting instruments have been designed to be as simple and functional as possible. The 545A Logic Probe, for example, uses a single lamp to indicate the various states possible on a digital signal path (HIGH, LOW, single pulses, pulse trains, open circuit).

Another main feature of a probe is its ability to “stretch” a 10 ns pulse to 100 ms so that the user can see it. This is accomplished by using the leading edge of a short pulse to trigger a circuit whose time delay is 100 ms. Single pulses cause the probe's lamp to flash once; pulse trains flash at ≤ 10 Hz regardless of frequency. The great benefit provided by probes is simply in knowing that pulse activity is present. Usually that is all the information needed.

However simple the probe may appear, it can't simplify many of the inherently complex problems of troubleshooting PC boards holding up to 100 IC's, or more. There are few substitutes for having good circuit documentation, plus some way to narrow down the fault area, such as the combined use of logic state analyzers, signature analyzers, troubleshooting trees, and finally node and gate troubleshooters that positively identify the single fault in a complex system.



The 545A Logic Probe Tip Indicator Lamp

LAMP ON



= LOGIC HIGH

LAMP OFF



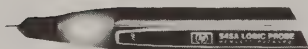
= LOGIC LOW

LAMP DIM



= OPEN CIRCUIT OR BAD LEVEL

LAMP FLASHES



PULSES:

— Single pulse: one flash

— Pulse trains: flashes at ≤ 10 Hz

The Pulse Memory

- Catches single pulses
- Indicates absence of a single pulse

1. Place tip on circuit under test
2. Press MEM/CLR; light goes out
3. Light comes on when a single pulse occurs.

MEM



CLR

The TTL/CMOS Switch

- Allows TTL/CMOS probing

1. Set switch to family under test
2. Attach supply leads to power source of family under test
3. Select TTL operation using CMOS supply by putting switch in TTL position

TTL



CMOS

The 548A Logic Clip

HP's 548A Logic Clip has proved to be successful because it's so easy to use, and so handy. It clips on to any TTL or CMOS IC and lets the user see up to 16 pins of an IC at once. This feature is particularly useful with counters and shift registers or around any circuit with a truth table that needs checking. To get optimum results, the circuit under test needs to be stopped so the user can check inputs versus outputs. This makes the clip really handy for both designers and technicians.

The clip does not stretch short pulses as does a logic probe or a current tracer. It does however allow users to check out an entire IC at a time, and gets its power from the circuit under test, and all automatically. There are no adjustments, switch settings, or knobs to turn.



Auxiliary Power Input:

- useful for ≥ 3 volt Cmos: make supply 1.5 volts more positive than circuit under test
- useful for minimizing current drain from circuit under test



LAMP ON = LOGIC HIGH



LAMP OFF = LOGIC LOW



LAMP DIM = PULSE ACTIVITY

(Brightness dependent on Duty Cycle)

Section III

Stimulus Response Testing

In the digital troubleshooting world the idea of stimulus-response testing is a relatively new one. Tools to measure logic states have existed for quite some time, but forcing a state change, especially on a line being held LOW is something that was difficult prior to the introduction of HP Logic Pulsers. To accomplish such a task meant disconnecting a device's input from the circuit, and then pulsing the input with a source. In practical terms the troubleshooter often unsoldered and lifted an IC leg, or cut a circuit trace, then used a pulse generator to drive a gate's input.

The "why" of such destructive techniques has to do with the internal structure of standard TTL gates. A TTL gate in its LOW state is a saturated transistor to ground. To move a TTL output HIGH requires a great deal of current drive. The catch here is that continuous high current tends to destroy the TTL gate's output transistor. So, it was usually safer and easier to simply disconnect a node driver from a circuit and replace it with a low current stimulus tool. The logic pulser changed this because it delivers both high current and low total energy by generating very short pulses sufficient to momentarily override TTL logic LOW states. The 10526T and 546A can both output high current, but pulse width is never sufficiently long to degrade a gate's performance, (the pulser will usually generate a TTL HIGH for only about 500 nanoseconds).

And so, stimulus-response testing using either of these powerful pulsers in digital circuits is as convenient as any technique devised for analog circuitry.

To help show how straightforward digital stimulus-response testing can be, the table on the next page outlines seven node and gate troubleshooting problems and how pulsers and other IC troubleshooters would be employed to pinpoint the fault.

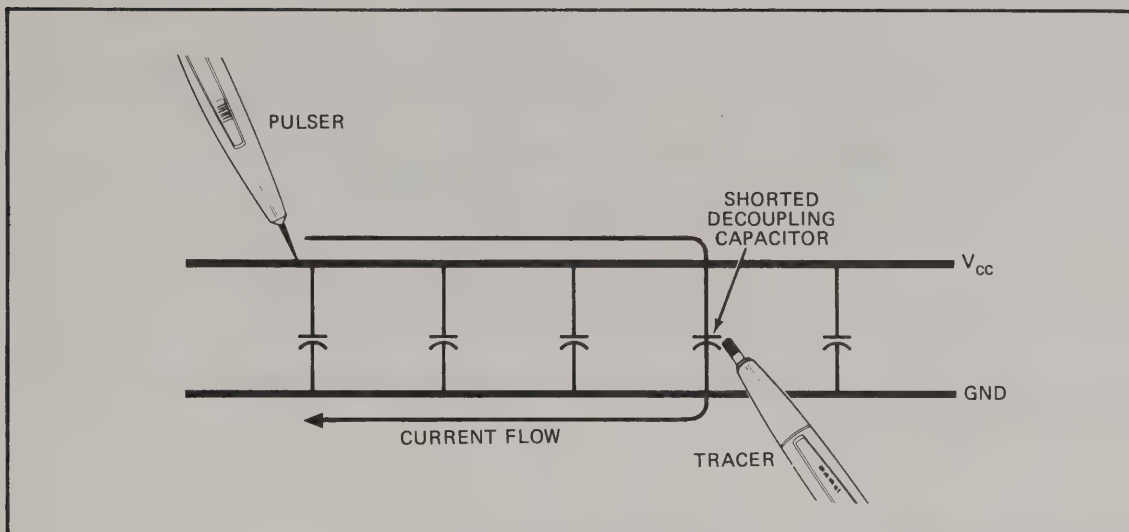
This section also contains several examples of typical failures to help you derive the maximum benefit from the IC troubleshooters.

Stimulus-Response Testing Using the IC Troubleshooters

FAULT	STIMULUS	RESPONSE	TEST METHOD
Shorted Node ¹	Pulser ²	Current Tracer	<ul style="list-style-type: none"> • Pulse node • Follow current pulses to short
Stuck Data Bus	Pulser ²	Current Tracer	<ul style="list-style-type: none"> • Pulse bus line • Trace current to device holding the bus in a stuck condition
Signal Line Short to Vcc or Ground	Pulser	Probe Current Tracer	<ul style="list-style-type: none"> • Pulse and probe test point simultaneously • Short to Vcc or Ground cannot be overridden by pulsing • Pulse test point, and follow current pulses to the short with tracer
Vcc to Ground Short	Pulser	Current Tracer	<ul style="list-style-type: none"> • Remove power from test circuit • Disconnect electrolytic bypass capacitors • Pulse across Vcc and ground using accessory connectors provided • Trace current to fault
Suspected Internally Open IC	Pulser ²	Probe	<ul style="list-style-type: none"> • Pulse device input • Probe output for response
Solder Bridge	Pulser ²	Current Tracer	<ul style="list-style-type: none"> • Pulse suspect line(s) • Trace current pulses to the fault (Light goes out when solder bridge passed)
Sequential Logic Fault in Counter or Shift Register	Pulser	Clip	<ul style="list-style-type: none"> • Circuit clock de-activated • Use Pulser to enter desired number of pulses • Clip onto counter or shift register and verify device's truth table
<p>1. A node is an interconnection between two or more IC's.</p> <p>2. Use the Pulser to provide stimulus, or use normal circuit signals, whichever is most convenient.</p>			



Vcc - Gnd Shorts



Shorts between Vcc and ground on a PC board have typically been located by using some of the following troubleshooting techniques:

- Hook a high current DC supply up to the PC board and see which traces change color, delaminate, or burn up.
- Measure micro-volt drops across active supply traces to see where the current is flowing.
- Replace all capacitors on the board.
- Replace all IC's on the board.
- Put the board in the "dog pile" and troubleshoot it on a rainy day.
- Scrap the board.

Scrapping the board seems extreme, but most people's experiences show that shorted decoupling capacitors account for the majority of supply-to-ground shorts, and faulty capacitors cause most of the shorts. But, if there are a lot of bypass capacitors (or, if you want to minimize component removal, and thereby limit damage to the PC board) it usually won't pay to take them out one at a time to find the shorted on. To help solve this problem HP invented the IC Troubleshooters.

So, to quickly find shorted parts on a board, use the 546A Logic Pulser and 547A Current Tracer (and refer to the troubleshooting tips below).

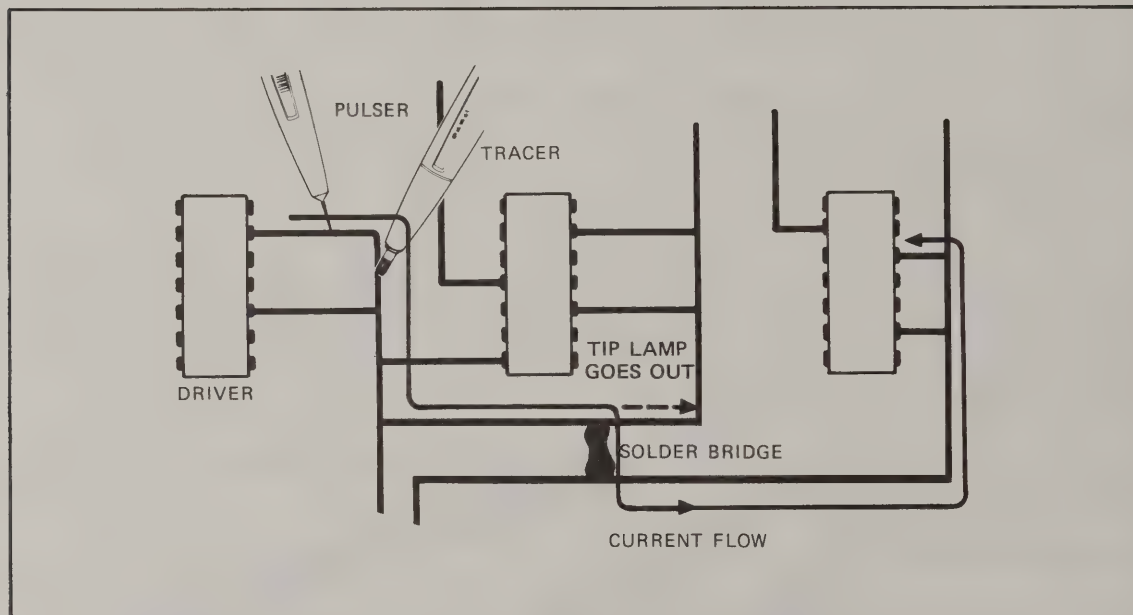
TROUBLESHOOTING TIPS:

- Remove power from the circuit. Power the pulser and tracer from a 5-volt supply.
- Lift one side of the electrolytics on the supply bus. This speeds up troubleshooting time by a factor of ten (electrolytics "eat" pulses creating many different current paths).
- Pulse across the power supply pins or across components in the corners. Use the cables and grabbers provided with the pulser for this purpose so your hands are free to move the tracer around. Moving the pulsing point around from corner to corner and tracing current from the pulsing point helps speed fault location on tough-to-solve faults.
- Because you're pulsing into a short, there is lots of current available. Put tracer sensitivity to 1 amp.

5. With boards where power enters through more than one connector, parallel current paths can exist. Moving the pulsing point around is helpful because the current path can change between the pulsing point and the short.
6. Sometimes a current path will seem to disappear. Several things can cause this situation to occur:
 - a) The PC board trace become wider and current "fans out", lessening the field intensity under the tracer tip.
 - b) The current may pass through a plated-through hole in the PC board.
 - c) Current "branches" and goes to several different places via several different paths; thereby lessening current density in the path you've been following.
7. When you think you've located the fault, verify it by moving the pulsing point **to** the short. No current paths should be detected elsewhere on the board if you pulse directly across a short.

As non-destructively as possible, remove the suspected component and verify that the Vcc to ground short no longer exists.

Solder/Gold/Copper Bridge Faults

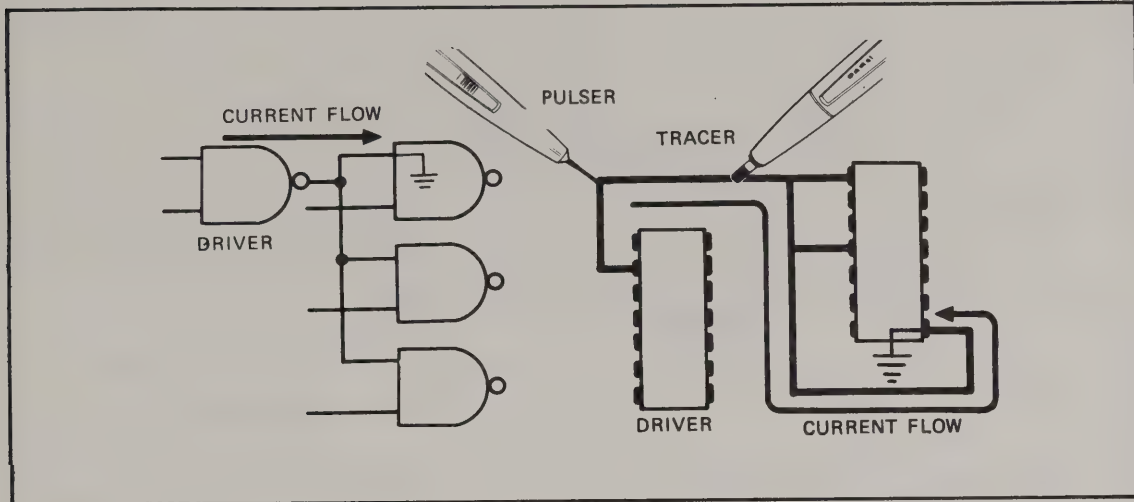


SOLDER/GOLD BRIDGES

With higher density PC boards, the occurrence of shorts between two nodes or a node and a ground has become commonplace.

1. Pulse the driver output on faulty node at desired pulse rate.
2. Adjust sensitivity of the 547A Current Tracer at the node driver output; use the current tracer to follow current pulses to short.
3. The light on the 547A Current Tracer will go out when the solder bridge is passed.

Node and Gate Troubleshooting Examples

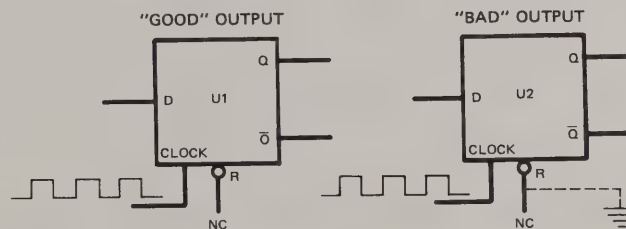


A frequently occurring problem in troubleshooting is a stuck node. In this example the problem is to determine if the driver is dead, or if a shorted input is clamping the node to a fixed value.

1. Use the probe and pulser to test the node's logic state and to see if the state can be changed (shorts to Vcc or Gnd cannot be overridden by pulsing).
2. Pulsing the node enables the user to follow current directly to the faulty input.
3. Set the current tracer reference level by adjusting tracer sensitivity until the light just lights with pulser on 100 Hz mode.
4. Use the current tracer to locate the fault.

Some Real Examples:

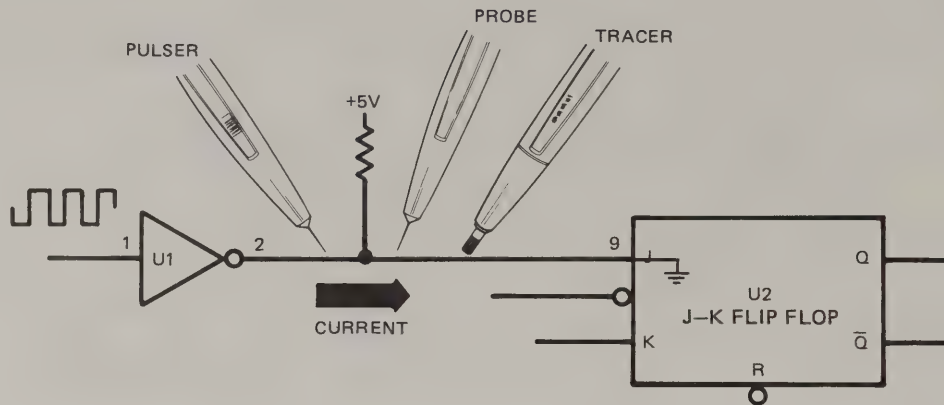
Example 1



Here are two D-Flip-Flops. One works normally, the other doesn't change output state although input conditions are identical for both.

- a) Use the pulser at the D input and probe Q and \bar{Q} to see if the outputs change. (In this actual example, they didn't.)
- b) The Reset line in the above case was found to be stuck in a LOW state by using a logic probe. Pulsing and probing simultaneously indicated the Reset line couldn't be driven HIGH, indicating the line was shorted to ground.
- c) Further use of pulser and current tracer showed that the area near the Reset line drew current when pulsed and that the D-Flip-Flop would not perform operations when the Reset line was pulsed.
- d) Using the pulser and tracer the operator found a hairline solder bridge from the Reset line to ground.

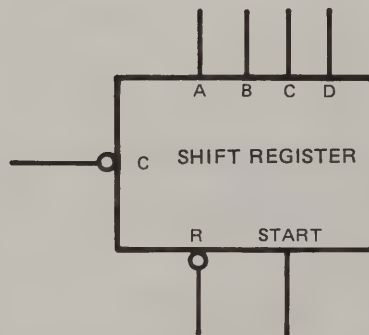
Example 2



The node between U1 and U2 was stuck LOW when measured by a logic probe, although probing revealed pulse activity at U1's input.

- Probe U1 pin 2. If no voltage activity is present, pulse pin 2 and see if the node's state can be changed.
- In this case the state couldn't be altered using a pulser so current was traced from U1-2 to U2-9, the J-K flip-flops input.

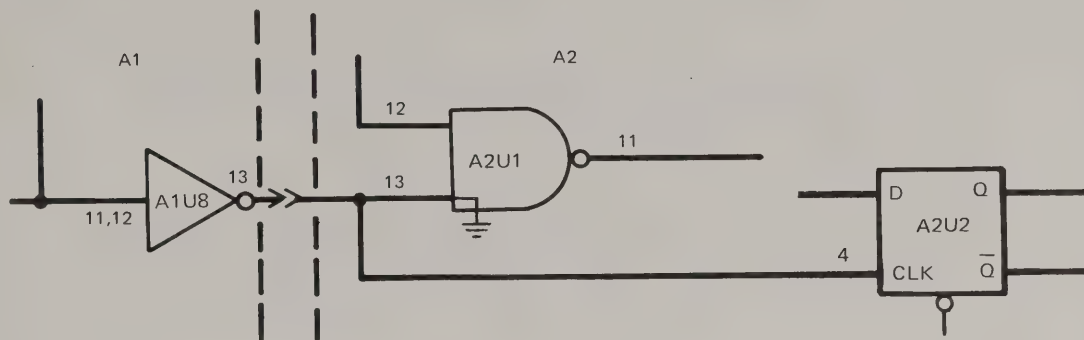
Example 3



Outputs A, B, C, and D are LOW; other circuit inputs appear normal.

- Use the probe and pulser to make sure A, B, C, and D aren't grounded (probe and pulse each pin — if ungrounded the states will be changed by the pulses).
- Probe other pins on the IC and check for normal/abnormal indications.
- Measure current at pins A, B, C, and D by pulsing each pin, and tracing to see if current flow is indicated from the pulser to the Shift Register.
- In this example all signals are normal except A, B, C, and D. They are stuck LOW, and are not indicating current flow, which suggests an internal failure in the IC, and not in the circuits connected to it.

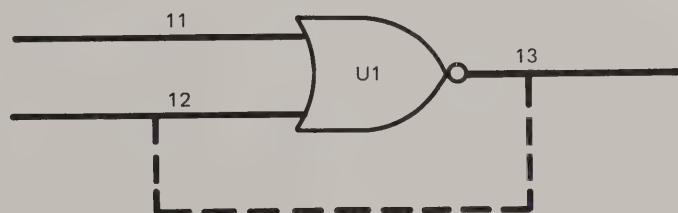
Example 4



Pin 13 of U1 is being held LOW. (In this case the node consisting of A1U8-13, A2U1-13 and A2U2-4 is spread over two PC boards.)

- Use the HP-10529A Comparator to find the faulty node. The comparator identifies A1U8-13 as bad allowing you to troubleshoot further.
- Probing and pulsing the node indicates it is stuck LOW.
- Pulsing and current tracing at A1U8-13 indicates current is flowing toward PC board A2.
- A2U1 is sinking current and holding the node LOW. As a result, U2 is not being clocked. The comparator located the failure (A1U8 pin 13), but it required the tracer to indicate current flow to verify A2U1 as the cause.

Example 5



U1 tests bad using the probe and pulser. The problem is to find out the nature of the fault before removing what appears to be an internally shorted IC.

- Pulse pin 12, and observe with the probe that pin 13 changes state but in the wrong direction (12 and 13 are in the **same** state).
- Pulse pin 12 and read current at pin 13, then, reverse the two instruments. Current is identical in both directions.
- Pins 12 and 13 are shorted together by a solder bridge on the back of the circuit board. Although originally located by pulser and probe, the tracer adds important information that keeps you from removing the IC.

Section IV

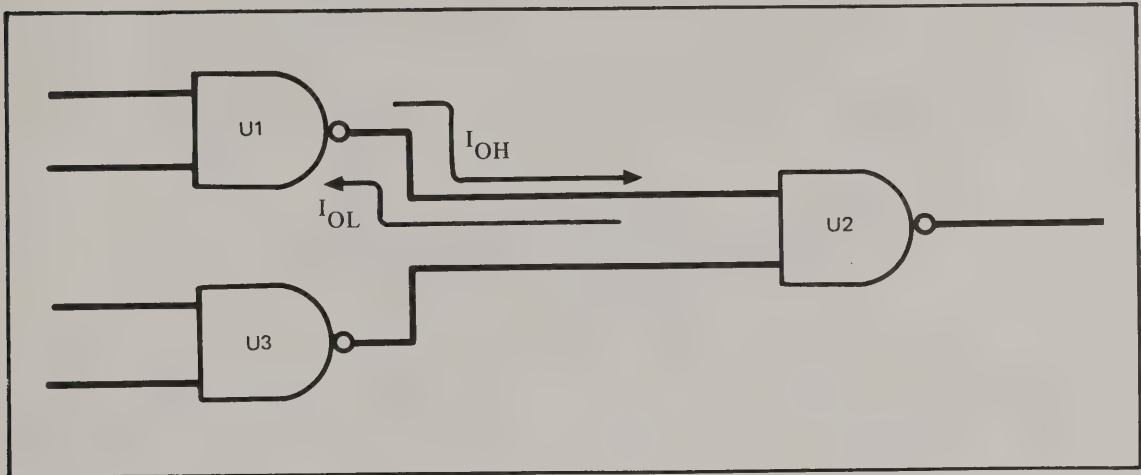
More Troubleshooting Information:

1. Current Flow Characteristics
2. Bus Troubleshooting

Section IV

Current Flow in Digital Circuits

Knowing the amount of current flow between logic circuit elements during logic HIGH and LOW states can help you when troubleshooting faults. The figures below shows current flow between two NAND gates under both HIGH and LOW states.



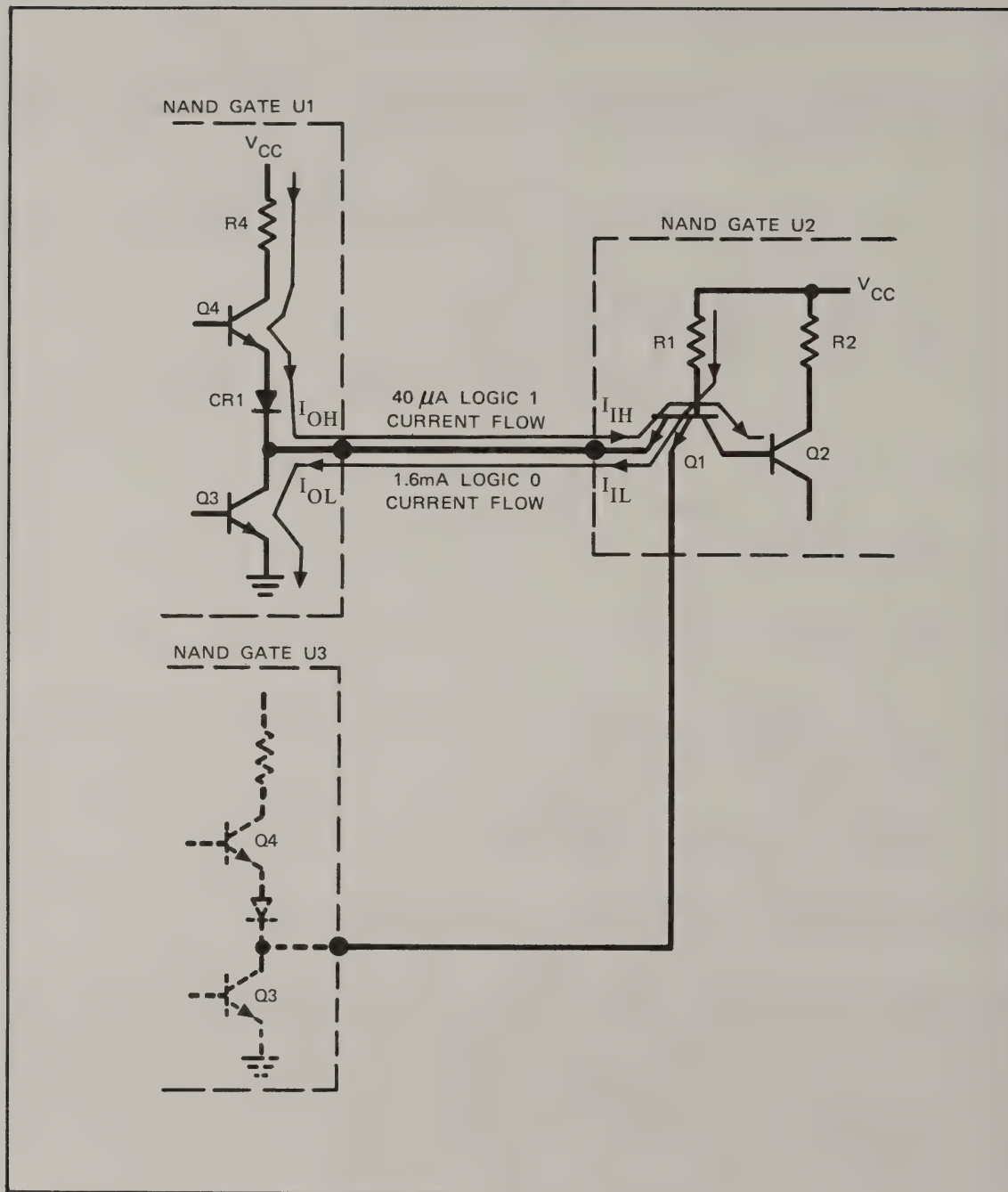
I_{OH} High level output current — the current flowing from the output while the output voltage is at logic 1. In TTL this is about $40\mu A$.

I_{OL} Low level output current — the current flowing into an output while the output voltage is at logic 0, normally about 1.6 mA in standard TTL for a fanout of one.

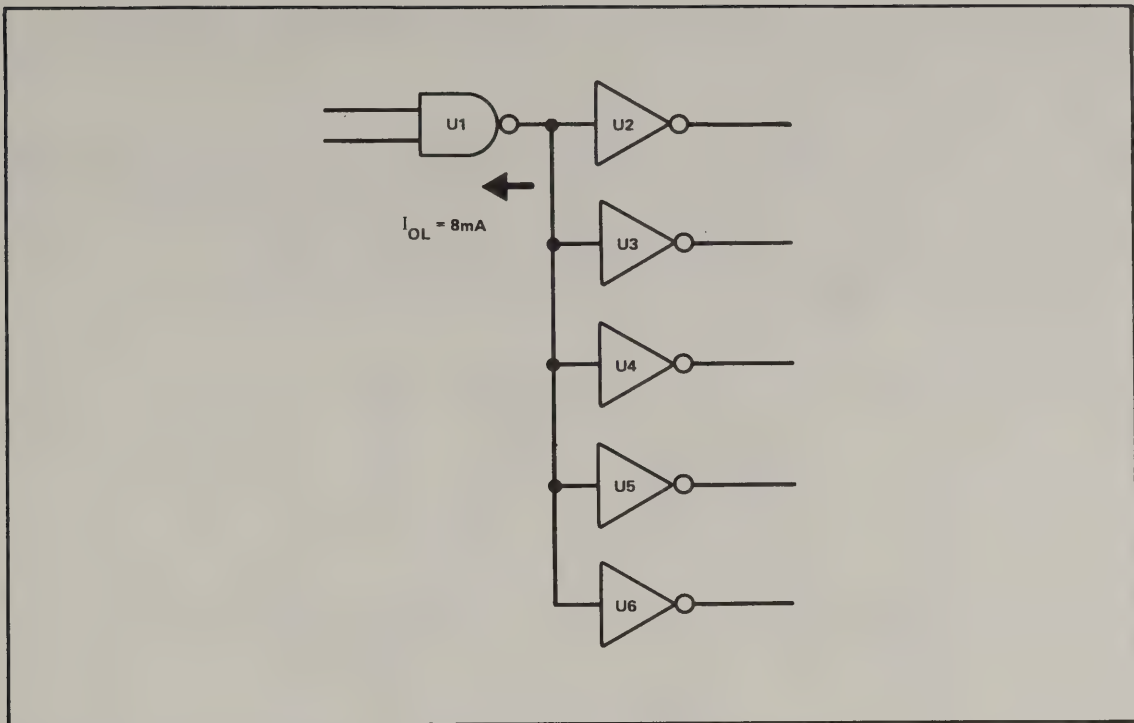
Due to the current tracer's inductive pickup it detects and displays the transitions between states. So, current pulses (transitions) must be present for troubleshooting purposes.

Since the 1.6 mA usually available in TTL is a relatively small amount of current, the 547A Current Tracer is designed to see transitions much smaller in amplitude. During troubleshooting however, current associated with all logic families tends to be much higher, up to 55 mA for standard TTL circuits looking into a short, for example. So, it is likely that only fault current will be seen in many cases, making the troubleshooting task simpler. A short at U2's input would result in 55 mA of current flowing toward U2 when U1 tries to go HIGH, and there would be no logic state change due to the short. Both conditions are measurable using the IC Troubleshooters.

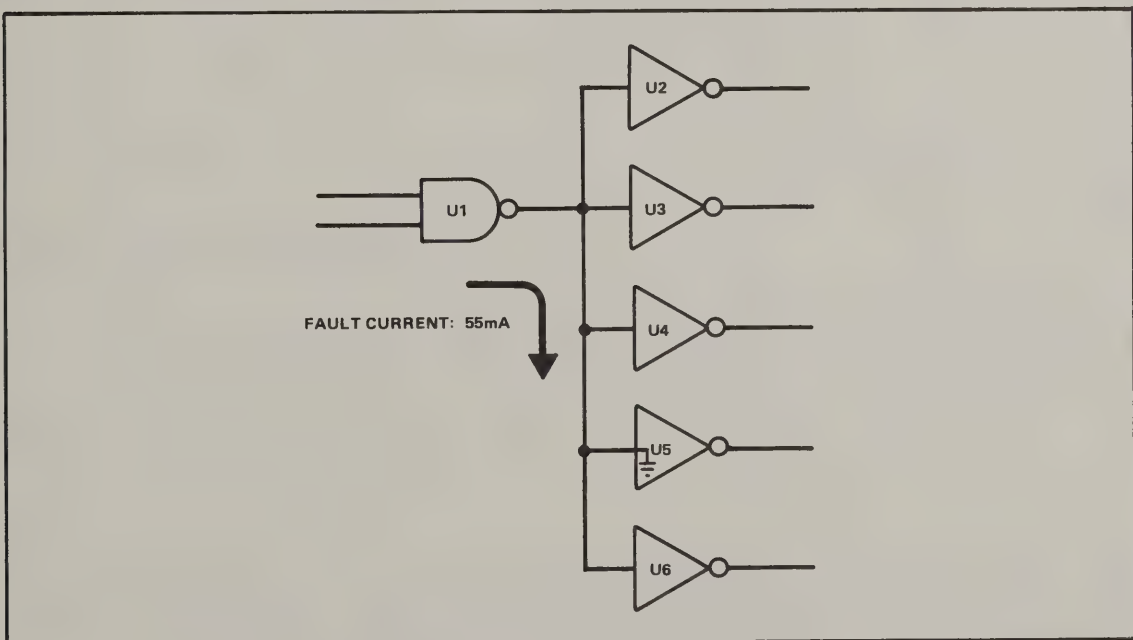
Here's the same circuit drawn to show the internal structure of the IC's:



When the output of U1 is at a LOGIC LOW state, Q3 is a saturated transistor to ground drawing about 1.6 mA. Q3 has the capability to drive up to 10 gates, and therefore to sink up to 16 mA of current during normal logic state operation.



When U1 goes LOW in the example above, its output transistor will sink 1.6 mA of current from each inverter. So, normal current here would be about 8 mA. Introducing a short circuit anywhere on the node consisting of the U1 output and the inputs to inverters U2-U6 would radically alter both the direction and magnitude of the current.

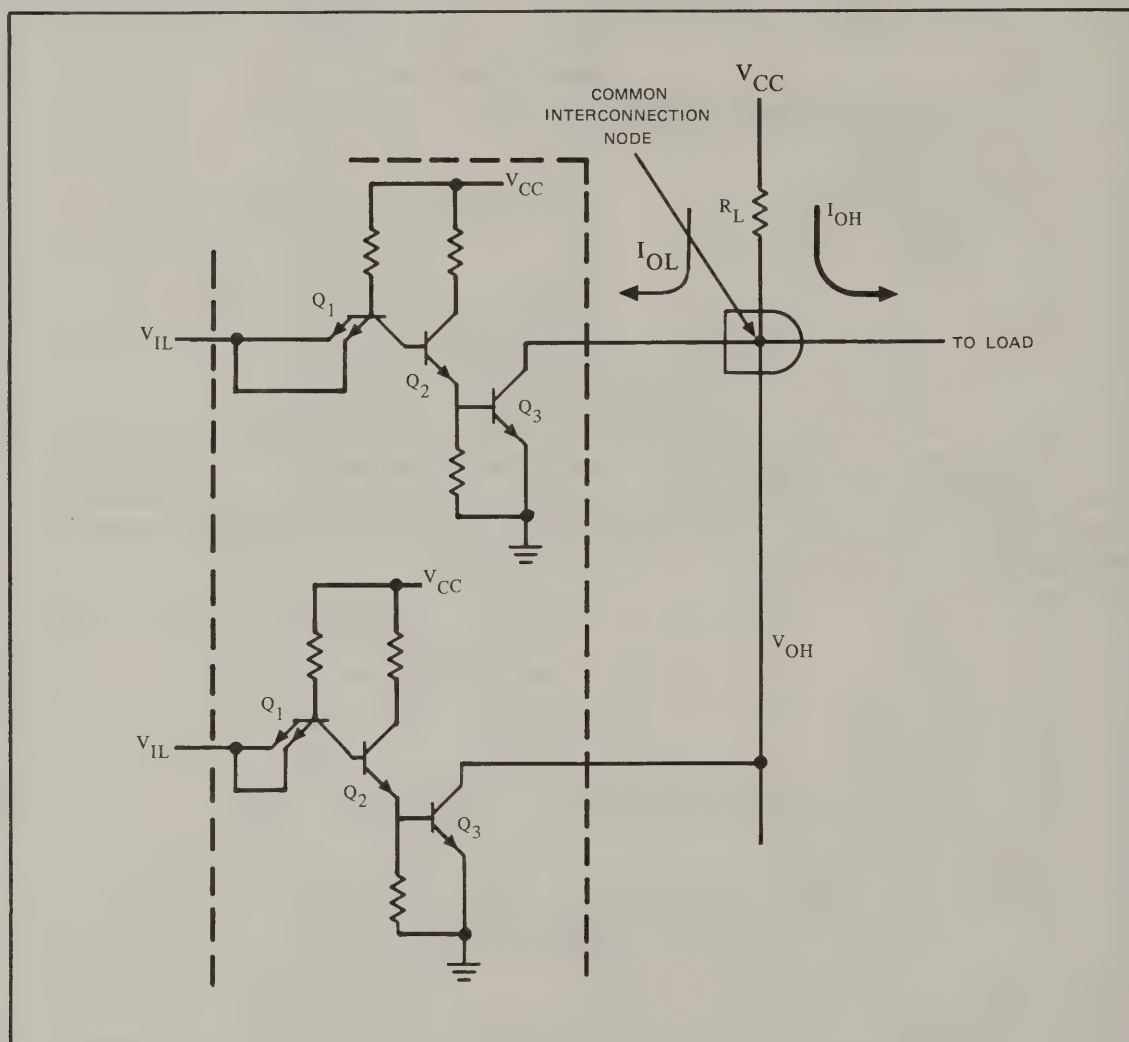


In practice, current flow for both normal and fault conditions will usually be **much more complicated** than these examples. There are some general rules, however, that help:

1. When you have a known bad node, the current generally exceeds other currents on the PC board by a wide margin.
2. Knowing the **source** and **sink** of current often quickly pinpoints the faulty component on a node, especially if a logic pulser is used as the current source.

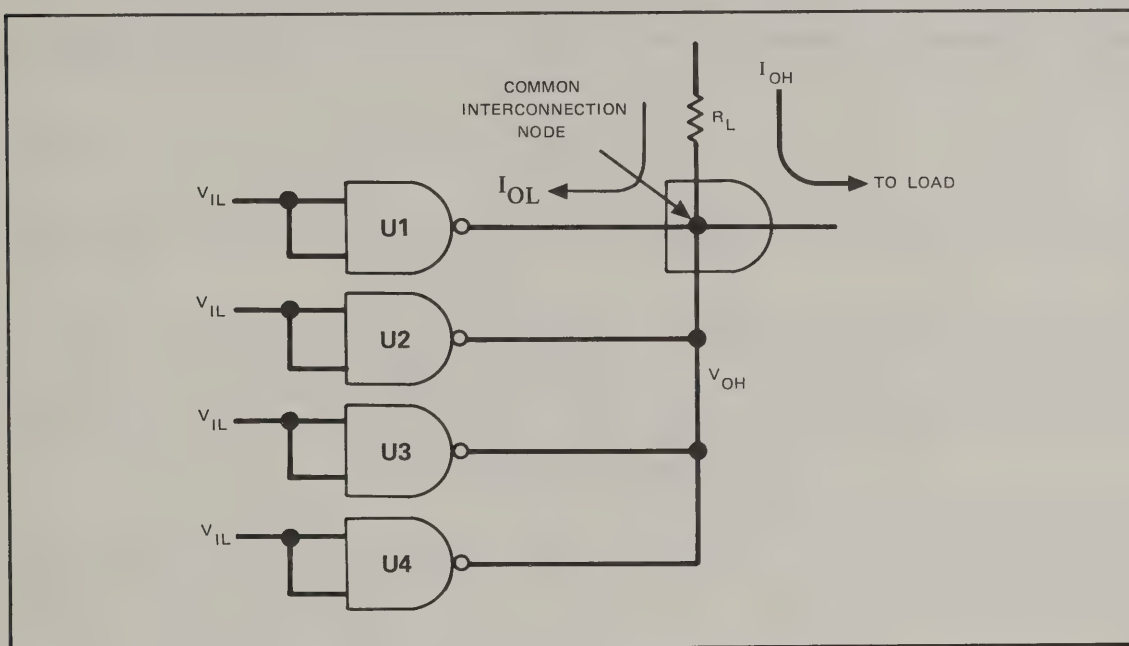
Open Collector Gates/Wired-And's, Wired-Or's

Prior to the wider use of bus structures like those found in microprocessor-based systems, the Wired-And was used a great deal in TTL applications. It is included only as a brief example here for those occasions you encounter it. The Wired-And employs an open collector circuit to allow designers to hook up a number of gates, any one of which can go LOW and control the bus.



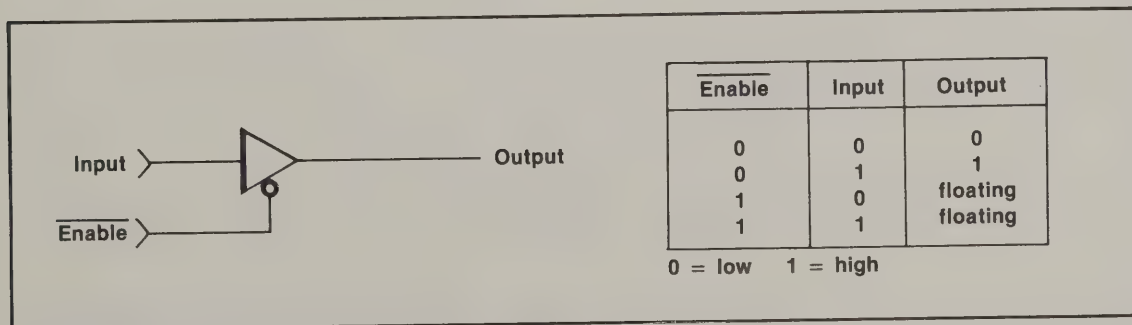
Open collector gates differ from other gates in that they do not have an active logic HIGH current source. Instead, the collector of Q3 is left unconnected, as shown above. Thus, the open collector gate can sink current in a logic LOW output state, but cannot supply any in a logic HIGH state.

When used in a circuit, several open collector gates are interconnected as shown below. To provide logic HIGH current, a pull-up resistor (R_L) is connected to V_{CC} . As long as transistor Q3 in every gate is turned off, the voltage at the common interconnection node is near V_{CC} (logic high), but when Q3 in any one gate is on, the voltage drops to logic 0. The result of this interconnection is that the common node acts as an AND gate in itself — it is high only when all of its inputs are logic HIGH. This is usually referred to as an implied, dot, or wired AND configuration. This circuit becomes a Wired-Or in TTL if the inputs and outputs are active low. In families other than TTL, a similar connection as shown below also performs the Or function. For these reasons, the terms Wired-And and Wired-Or are often used to mean the same thing. A similar interconnection of outputs is also used with the gates of logic families other than TTL, in which case it also performs an OR function. As a result, the interconnection shown is sometimes called a wired OR.

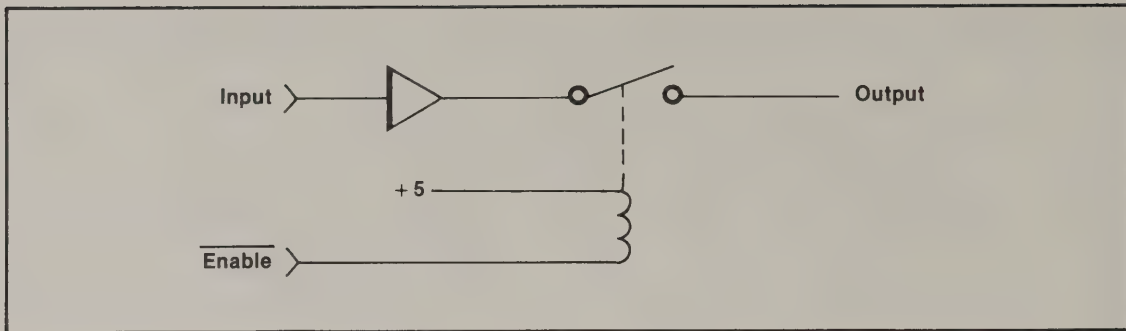


Three-State Buses

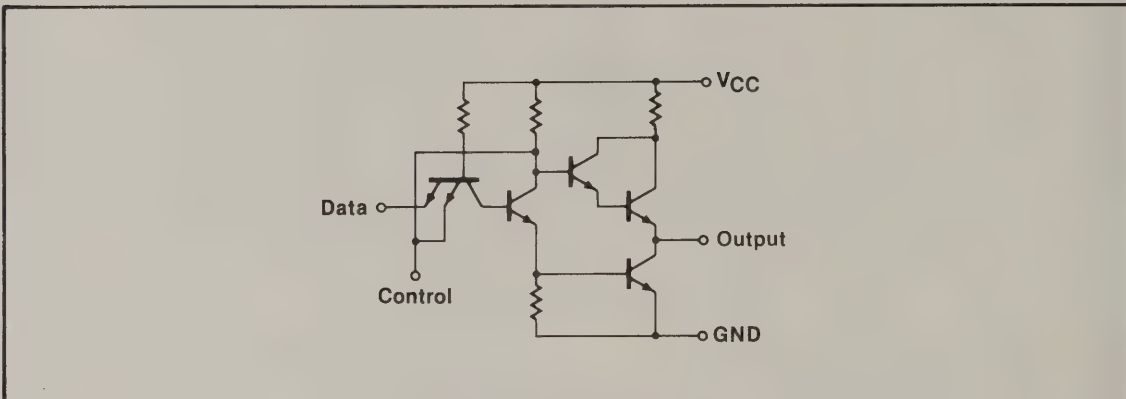
A further development of the Wired-And idea is shown below. This is the three-state driver found extensively in microprocessor circuitry. The three-state driver is built into many of the IC's of a microcomputer to allow common bus usage by all the computer's devices. A Read Only Memory (ROM), for example, has a three-state driver on each of its data output lines. When the ROM is enabled, it puts data on the microcomputer's data bus by turning on the chip's internal three-state driver outputs.



a) Three-state bus: truth table

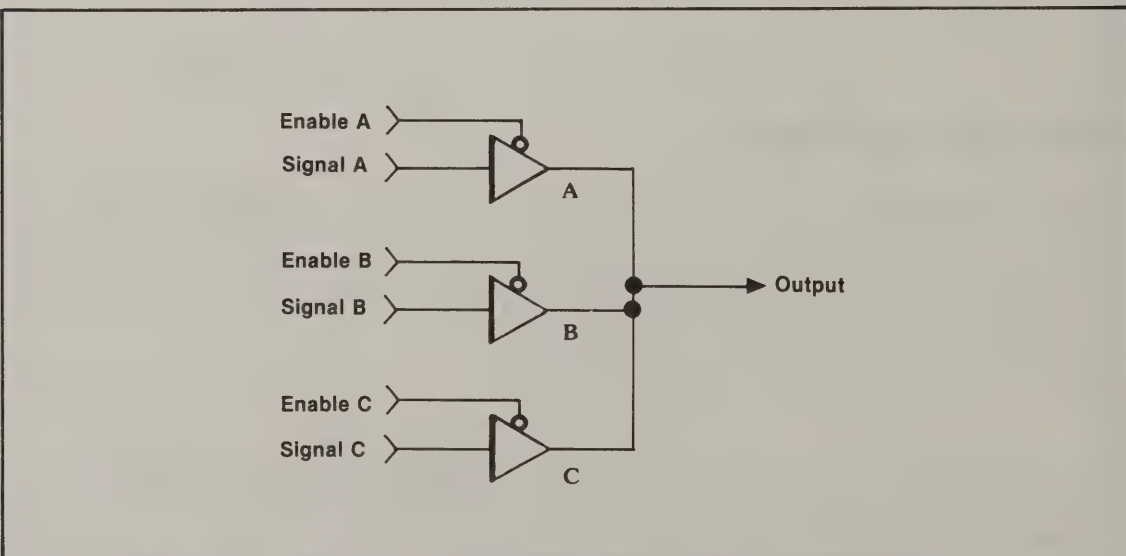


b) Three-state bus: equivalent circuit



c) Three-state bus: internal circuitry

Three-state buffer/driver chips are also available for connection in a circuit like the one below:



d) Three-state bus: several drivers bused together. Only one driver is enabled at a time.

This circuit is connected in the same fashion as the Wired-And example shown earlier. The difference in this circuit is that it takes an enable signal at each buffer to turn on one of the gates; otherwise, the outputs remain in the open state.

Troubleshooting Bus Structures

Three-state drivers and Wired-And's are often difficult to troubleshoot. That's because a bus structure can be controlled by one faulty device which causes the entire bus to be faulty. Since all points on the bus are at the same voltage potential, voltmeters, oscilloscopes and other voltage measuring instruments can't indicate which component is causing the bus to be stuck.

Talkers or Listeners?

The first decision to make when troubleshooting bus structures is to decide if the fault exists in the buses' drivers or listeners. The paragraphs below are intended to give you some general information about talkers and listeners so you can zero in on a bus fault. The techniques described here also depend on use of the IC Troubleshooters.

The Bus Driver: Dead or Alive?

Do you find pulse activity on the bus driver's inputs? Is the driver enabled? Does the driver respond to a stimulus?

These questions are answerable using the probe and pulser to first see the state of the circuit, and then to see if the state changes when the circuit is pulsed. Be sure you can enable or disable the driver without stressing it either physically or electrically. Also, check multiple inputs to drivers to make sure you have control when you want to stimulate the circuit. If you find this impossible to do because of physical packaging of the circuit, check the bus listeners first.

Often, use of PC board testers, logic analyzers, or signature analyzers will have led you to suspect a particular faulty bus line. The next sections should give you tips to make quick checks of stuck lines and further isolate the fault.

Stuck Low/Stuck High

When a bus is stuck in one logic state, it is not necessarily inactive. A bus stuck LOW might be shorted to ground at the input to one of the bus listeners. If this were so, the bus driver would still be trying to drive the bus, and failing. The driver wouldn't be able to alter the bus logic state, but there would be a lot of current flowing on the bus from the driver to the fault. This current activity is traceable using the 547A Current Tracer. If the driver is good, but no current pulses are available on the bus for tracing purposes, use a 546A Logic Pulser at the driver output, and then trace the current flow from the pulser to the fault.

Use the IC Troubleshooters to check bus listeners as your next step after eliminating shorts as a bus problem. If the line wasn't shorted, verify if listeners on the bus respond to inputs. An open could exist there, on the bus line itself, or perhaps the bus driver is faulty. Use the 546A Pulser to stimulate lines without activity, then monitor the logic states and current activity present on the bus to pinpoint open lines and open listener inputs using the 545A Probe and 547A Current Tracer.

Open Circuits

A stuck bus can occur due to an open circuit at one of three points: the bus driver output, the bus line itself, or a listener input. Generally these can be pinpointed by pulsing and probing, or by using the Current Tracer to see the existence or absence of current at inputs or outputs.

General Tips

Finally, the table below contains several generalized bus troubleshooting procedures. They are not likely to describe all buses, or even a specific bus you will run into. There is great variety in bus design. Use this data to help figure out the principles of the bus you are troubleshooting to help speed the solution to your bus fault.

General Tips on Troubleshooting Bus Structures

Type of Bus Driver	Troubleshooting Tips
Open Collector (Wired-AND/OR)	<ol style="list-style-type: none">1. Open collectors can sink current, but not source it so a pull-up resistor to V_{CC} is connected to the output.2. Disable driver input(s)3. Pulse output(s)4. Faulty driver will draw the most current
Single Driver	<ol style="list-style-type: none">1. Driver can both source and sink current2. Pulse input(s)3. Probe output(s) for logic state changes, OR4. Current Trace output(s) for amplitude and the direction of the current path5. Determine if driver is dead or bus is stuck6. Replace dead driver, OR7. Pulse and Current Trace at output to pinpoint bus fault
Three-State Buffer (With source and sink capability)	<ol style="list-style-type: none">1. Disable driver inputs2. Pulse bus output lines3. If one output draws current, verify if it is faulty <p style="text-align: center;">OR</p> <ol style="list-style-type: none">1. Enable drivers2. Pulse driver inputs individually3. If one output fails to indicate current flow, verify if it is open.

General Notes

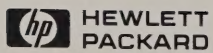
These notes are intended to provide a general overview of the project and its objectives. They are not intended to be a detailed technical specification or a project plan. The project is a study of the effects of the proposed development on the surrounding environment. The study will be carried out in accordance with the requirements of the relevant legislation and standards.

General Notes

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General Notes on Transferring Bus Strips

Type of Transfer	Transferring Fee
One-way transfer	£1.00
Two-way transfer	£2.00
Three-way transfer	£3.00
Four-way transfer	£4.00
Five-way transfer	£5.00
Six-way transfer	£6.00
Seven-way transfer	£7.00
Eight-way transfer	£8.00
Nine-way transfer	£9.00
Ten-way transfer	£10.00
Eleven-way transfer	£11.00
Twelve-way transfer	£12.00
Thirteen-way transfer	£13.00
Fourteen-way transfer	£14.00
Fifteen-way transfer	£15.00
Sixteen-way transfer	£16.00
Seventeen-way transfer	£17.00
Eighteen-way transfer	£18.00
Nineteen-way transfer	£19.00
Twenty-way transfer	£20.00



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